Final Report

1. ADMINISTRATIVE

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Project title: Very Fine Resolution Dynamical Downscaling of Past and Future Climates for Assessment of Climate Change Impacts on the Islands of Oahu and Kauai
Agreement number: G13AC00363
Period of performance: 9/1/2012 – 8/31/2015 (with one year no cost extension)
Total cost: $204,404
Date of report: 10/01/2016

2. PUBLIC SUMMARY

We provide the fine (800 m by 800 m pixel) resolution climate information for the islands of Oahu and Kauai based on very high resolution computer model simulations. The projected future climate changes by the late 21st century (2080-2099) forced with a high emission scenario (RCP8.5) and a medium emission scenario (RCP4.5) are delivered. The surface air temperature (SAT) is projected to increase by 1.5 – 2.0 °C for RCP4.5 and 3.0 – 3.5 °C for RCP8.5 over both Kauai and Oahu, slightly higher than over the neighboring ocean. The SAT increases more on leeward side than on the windward side. The projected future changes in rainfall over both islands in the RCP8.5 scenario exceed 15% in some locations and are generally positive on the windward slope and negative in the leeward areas. Projected changes in the RCP4.5 scenario follow the same pattern but are smaller. Note that over much of the area of the islands the projected rainfall changes are relatively small and statistically insignificant. We find that daily extreme rainfall events are likely to increase over both islands.

3. TECHNICAL SUMMARY

This project provides the best possible dynamically downscaled recent past climate and projected future climate change in rainfall, surface sensible heat fluxes and evaporation, radiative fluxes, wind, and temperature at small horizontal scales for the islands of Oahu and Kauai by the late 21st century using a very high resolution regional climate model. In addition to the reconstruction of recent past climate, estimates of changes in seasonal mean climatology as well as the frequency of extreme events under future emission scenarios are also produced. The basic results are supplemented by interpretation of the mechanisms involved in the high-resolution distribution of past climate and projected climate changes together with an assessment of the robustness of the projections.

4. PURPOSE AND OBJECTIVES

The research responds directly to the "Regionalized Climate Modeling" area in the PICSC focus. In this project, we extended our previous efforts supported by NOAA Pacific RISA and PICCC and focused on four objectives: (i) to analyze and improve the Hawaiian Regional Climate Model (HRCM)'s skill in simulating synoptic systems that cause extreme rainfall and windstorms in the Hawaiian region; (ii) to perform very high-resolution dynamical downscaling for Oahu and Kauai to better capture the fine-scale climates required for studies of possible effects of global warming on native ecosystems and for a variety of resource management issues; (iii) to investigate the projected impact of global warming on mean climate and extreme climate events in the Hawaiian region; (iv) to work with partners to use our fine-scale climate projections in an ecosystem service model to evaluate the implications of anticipated climate change for ecosystem services.

5. ORGANIZATION AND APPROACH

Following steps have been conducted in order to skillfully downscale the present-day climate and projected future climate change for Kauai and Oahu.

(1) The setup of the regional climate model. We configured the Weather Research and Forecast model (WRF) with triply-nested meshes (Fig. 1). The outermost domain is large enough to cover almost the whole tropical and subtropical areas from the central Pacific to the western Pacific. The intermediate domain has 4-km horizontal resolution, and the innermost domain has a horizontal resolution 0.8 km. The WRF model is widely used as a regional climate model to downscale the region climates in various regions all over the world. We developed a newly improved Tiedtke scheme for cumulus parameterization to better simulate tropical cyclones (TCs), especially TC genesis in the 20-km domain. The flow chart for the whole experimental designs is shown in Fig. 2. The driving fields for the atmosphere are from NASA Modern-Era Retrospective Analysis for Research and Applications (MERRA, Rienecker et al. 2011) reanalysis, and the sea surface temperature (SST) is from NOAA. Variables in the driving fields include temperature, wind, geopotential height, water vapor, etc. (Fig. 2a). For the future runs, the monthly-mean global warming signals are added to the present-day driving fields. This approach is called the Pseudo-Global-Warming method (Fig. 2b) and has advantages as briefly described below.

(2) Pseudo-Global-Warming (PGW) method. We adopted the PGW approach rather than a more straightforward dynamical downscaling applied directly to present day and future scenario integrations with an individual global model. State-of-the-art global coupled models when run freely generally display large biases in the simulated mean SST (with magnitudes as large as ~2K or more in many locations, e.g., Ashfaq et al. 2011) and other variables (e.g., Lauer and Hamilton 2013). Such biases may matter significantly for future projections (Sato et al. 2007; Ashfaq et al. 2011). By using observed SSTs and lateral boundary conditions the PGW approach allows one to avoid potentially serious errors in reproducing the observed present day climate (Kimura and Kitoh 2007). The other major advantage of the PGW approach is that it allows the large-scale forcing of the model to be based on the multimodel ensemble mean Global Warming Increments (GWIs). Lauer et al. (2013) conducted downscaling experiments with the outermost mesh of the HRCM using GWIs from 10 individual global models and compared the results with that from experiment using the multimodel mean GWI. Lauer et al. (2013) showed that despite a fairly large intermodel spread in the simulated climate changes, a single downscaling experiment using a multimodel mean GWI gives quite similar results to the ensemble mean of downscaling experiments using warming increments from each of the individual global models.

(3) The choice of the GWIs. The GWIs are a function of location, altitude and calendar date and were computed as the averaged global model simulated 2080-2099 results minus the 1990-2009 results. The monthly mean GWIs are interpolated linearly in time before being added to the 6-hourly reanalysis data used to create the lateral boundary conditions or daily SST data to create ocean surface boundary conditions for the HRCM. We used results from 12 CMIP5 models that provided all data needed for specifying the climate change contribution to the boundary conditions in the HRCM. The selection of these 12 models was based on the availability of the atmospheric components (e.g., 3D temperature, geopotential height, wind, specific humidity, 2-m temperature, 2-m specific humidity and 10-m wind speed). We chose one model from each available research center to enlarge the inter-model variability.

6. PROJECT RESULTS

(1) Present-day evaluations and future projections at Lihue and Honolulu airport

Figure 3 shows the topography and land use/cover for Oahu and Kauai. It is important for the model to realistically resolve the topography and land use/cover. The Lihue airport and Honolulu airport have the hourly Meteorological Terminal Aviation Routine Weather Report (METAR). The historical METAR hourly reports are used to evaluate the present-day simulation. The hourly data are used to compose the daily data. Figure 4 shows the frequency of the daily observed (red curve) and daily simulated present-day (blue curve) surface atmospheric elements, including mean surface air temperature (SAT_{mean}), minimum surface air temperature (SAT_{min}), maximum surface air temperature (SAT_{max}), mean surface specific humidity (Q_2), mean surface wind speed (SWS_{mean}), and rainfall. We chose the nearest grid with 'Mixed Shrubland/Grassland' to the METAR locations. As we can see overall the biases are very small.

The projected future changes of the surface variables are shown in Fig. 5. The SAT and Q_2 are both projected to increase significantly; this is a direct effect of the future greenhouse gas-induced warming. The SWS is projected to increase slightly. The extreme precipitation is likely to increase as indicated in Fig. 5.

Figure 6 shows the 20-yr interannual variations of the SAT_{mean}, SWS_{mean}, and rainfall for observations (red) and present-day simulations (blue) based on the monthly data. The curve is plotted with 6-month running average. The correlation coefficient (R) is high for SAT_{mean} and $SWS_{mean..}$ However, the R is relatively low for rainfall at both Lihue and Honolulu stations, as well as the Root Mean Square Error (RMSE).

(2) The projected future changes of SAT, rainfall and evapotranspiration

The projected SAT increases by 1.6 – 1.9°C for RCP4.5 and 3.1 – 3.6°C for RCP8.5 over both Kauai and Oahu by the end of 21st century (Fig. 7). The SAT over the land is projected to increase by 0.1 – 0.2°C more for RCP4.5 and 0.1 – 0.5°C more for RCP8.5 over land than that over the neighboring water. Also, the SAT increases more on leeward side than on the windward side (Fig. 7). The simulated present-day precipitation over Kauai is close to the observations from the Hawaiian Rainfall Atlas (Frazier et al. 2015) in terms of both the spatial distribution and magnitude (Figs. 8a and b). The projections show that the windward side gets wetter and the leeward side gets drier under the global warming. However, the changes for most areas are not statistically significant as measured by the paired student t-test. One possible reason is that the use of the large outermost domain we applied makes the internal variability large to dominate the local topographic forcing. Indeed, the local forcing and the synoptic forcing compete each other and even have opposite effects on rainfall. All these make the difference between the present-day rainfall and projected future rainfall not consistently positive or negative, leading to the projected rainfall changes statistically insignificant at many, but not all, locations. Similar results are found for Oahu (Fig. 9). The evapotranspiration (E) is also simulated for the present-day and projected future changes by the HRCM (Fig. 10). The E over windward side is projected to increase but that over some parts of the leeward side is projected to decrease, partly due to the projected changes in rainfall and consequent reductions in soil moisture.

7. ANALYSIS AND FINDINGS

The present-day climate of Kauai and Oahu is dynamically downscaled using the HRCM and the future climate is projected with the PGW method. Two future warming scenarios are applied in the projections, e.g., RCP4.5 and RCP8.5. The main findings are summarized below:

(1) The configured HRCM is capable of simulating the basic climate features reasonably well.
(2) The SAT increases by 1.6 – 1.9°C for RCP4.5 and 3.1 – 3.6°C for RCP8.5 over both islands with high confidence.
(3) The daily minimum and maximum SATs significantly increase at both Lihue and Honolulu airports. The future extreme rainfall events are likely to increase.
(4) The projected future change of rainfall is not significant in most areas over both islands, but the projections are statistically significant for the locations with the largest changes (exceeding 15% of current climatological rainfall) in the RCP8.5 scenario.
(5) The projected future evapotranspiration increases over most of the windward areas.

8. CONCLUSIONS AND RECOMMENDATIONS

We have projected the climate change by the late 21st century for islands of Kauai and Oahu using the regional climate model HRCM in this project. We have high confidence in the projected future daily mean surface air temperature (SAT) changes over the islands of Kauai and Oahu as well as the daily maximum and minimum SATs. Although we have relatively low confidence in the projected future rainfall changes, we believe that the daily extreme rainfall events are likely to increase. Both the local topographically-controlled response and the synoptic scale response to the global warming are important for determining how rainfall patterns will change. The uncertainties in the projected future changes and the effect of the prescribed interannual/decadal variations in the driving field through the lateral boundaries need to be evaluated in future studies.

9. MANAGEMENT APPLICATIONS AND PRODUCTS

We expect that the dynamically downscaled atmospheric and land surface data will be used to force application models to assess the impacts of climate change on hydrometeorological and ecological systems by other research groups.

10. OUTREACH

The paper entitled “Does the island scale matter in response to the future global warming?” is in preparation.

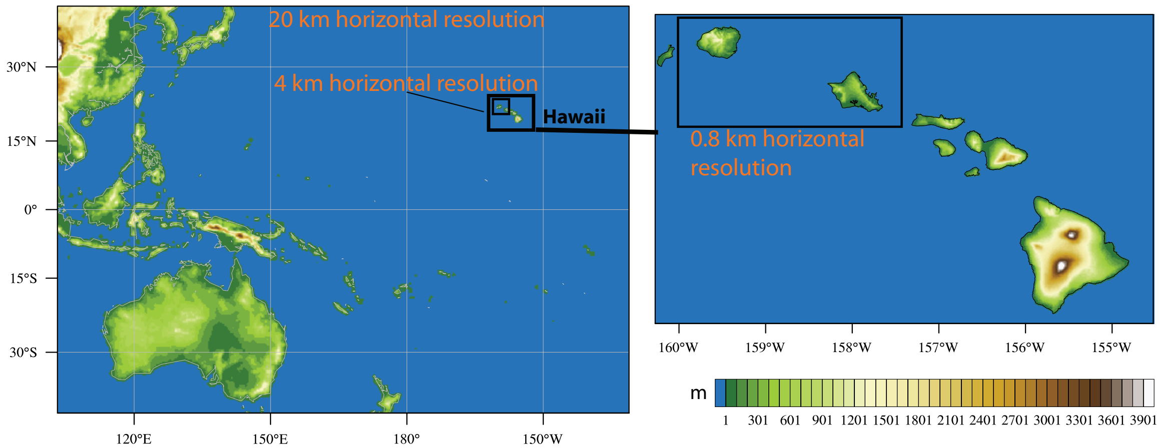

Figure 1. The configuration of the model domains for the simulations.

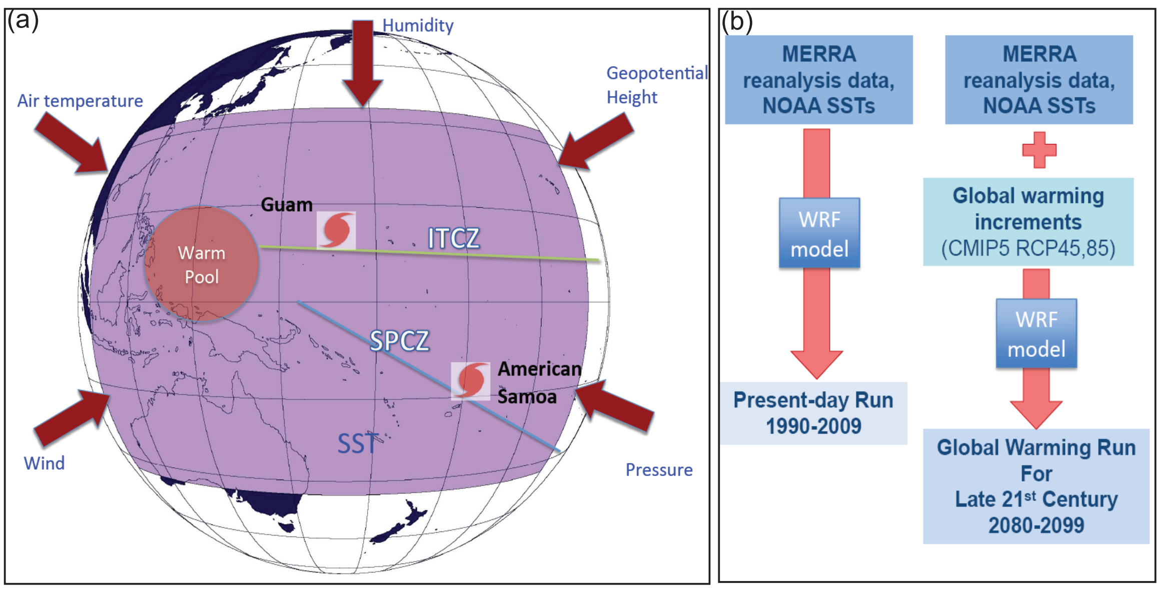

Figure 2. The CMIP5 multi-model mean increments are added to the lateral boundary conditions (a). The flow chart for the dynamical downscaling is shown in (b).

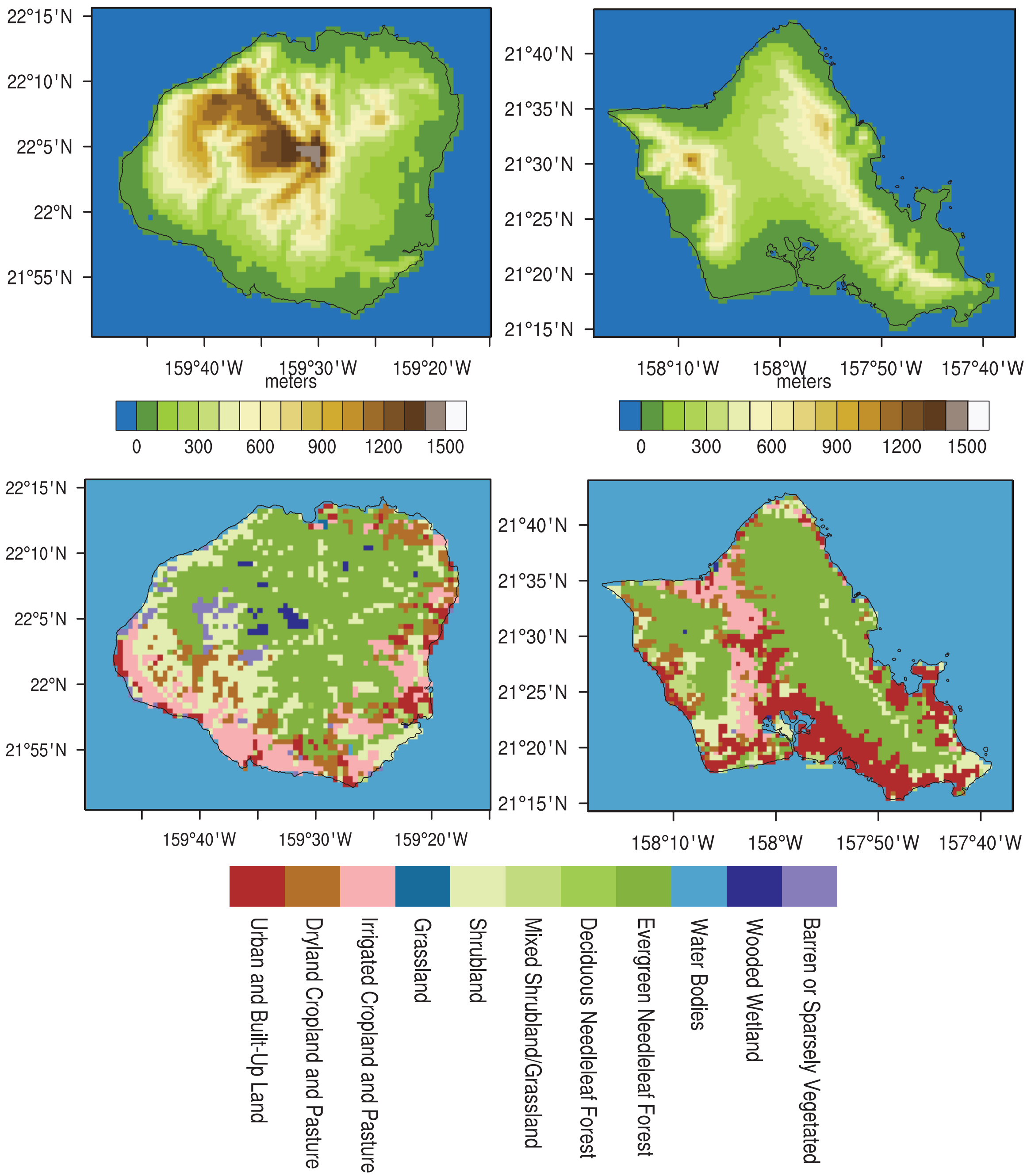

Figure 3. The terrain height (meters) of the innermost domain (0.8 km) for Kauai (top left) and Oahu (top right). The land use/cover map for Kauai (bottom left) and Oahu (bottom right) used in the simulations.

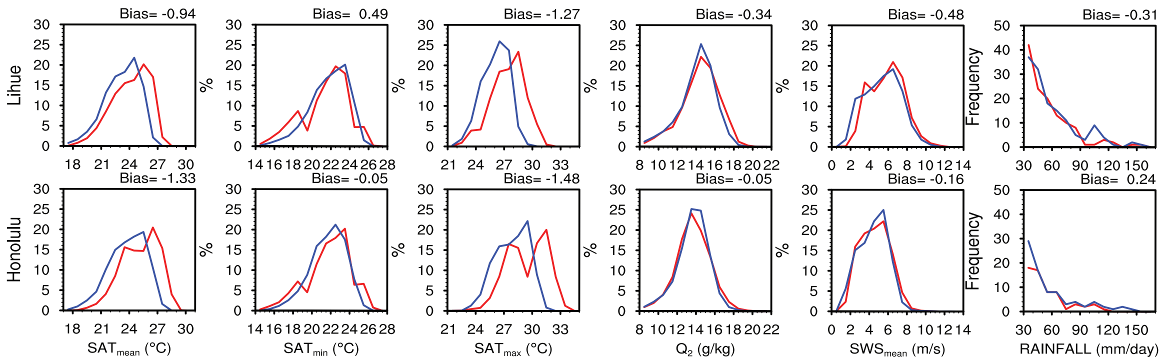

Figure 4. The simulated (blue line) and observed (red line) frequency for daily mean surface air temperature (SAT_{mean}), daily minimum SAT (SAT_{min}), daily maximum SAT (SAT_{max}), daily mean specific humidity (Q_2), daily mean surface wind speed (SWS_{mean}) and daily precipitation above 30 mm/day for Lihue and Honolulu airports, respectively.

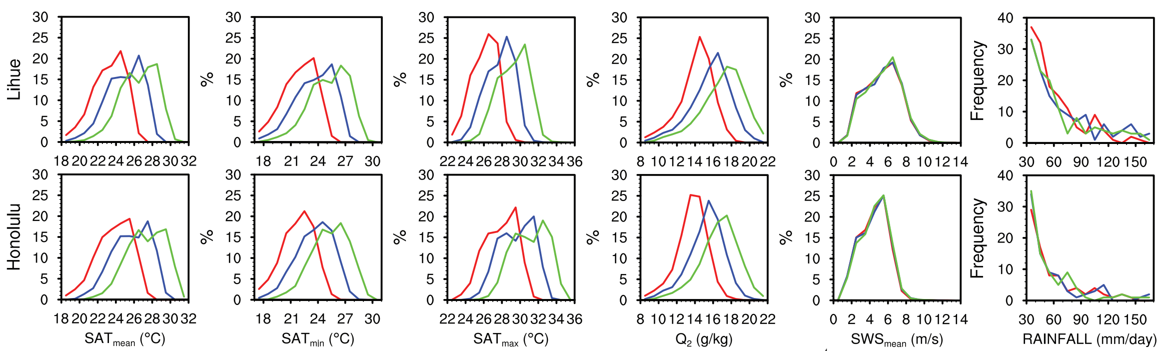

Figure 5. The simulated present-day (red) and projected late 21st century climate (blue: RCP4.5; green: RCP8.5) frequency distributions for daily mean surface air temperature (SAT_{mean}), daily minimum SAT (SAT_{min}), daily maximum SAT (SAT_{max}), daily mean specific humidity (Q_2), daily mean surface wind speed (SWS_{mean}) and daily precipitation above 30 mm/day for Lihue and Honolulu airports, respectively.

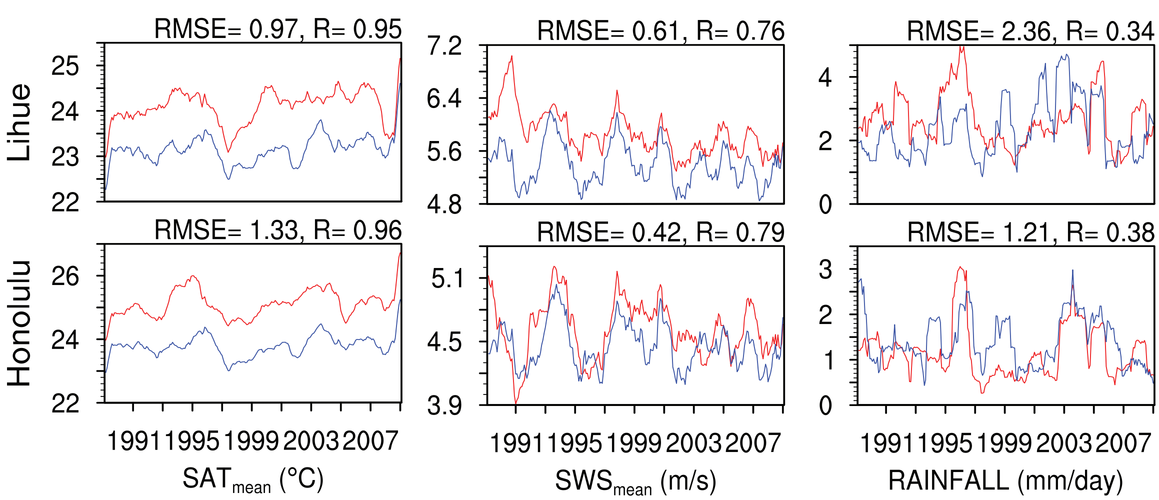

Figure 6: The interannual variations of SAT_{mean}, SWS_{mean}, and rainfall for Lihue and Honolulu airports, respectively. The red curve is for observations, and the blue curve is for simulation in the same time period (1990-2009).

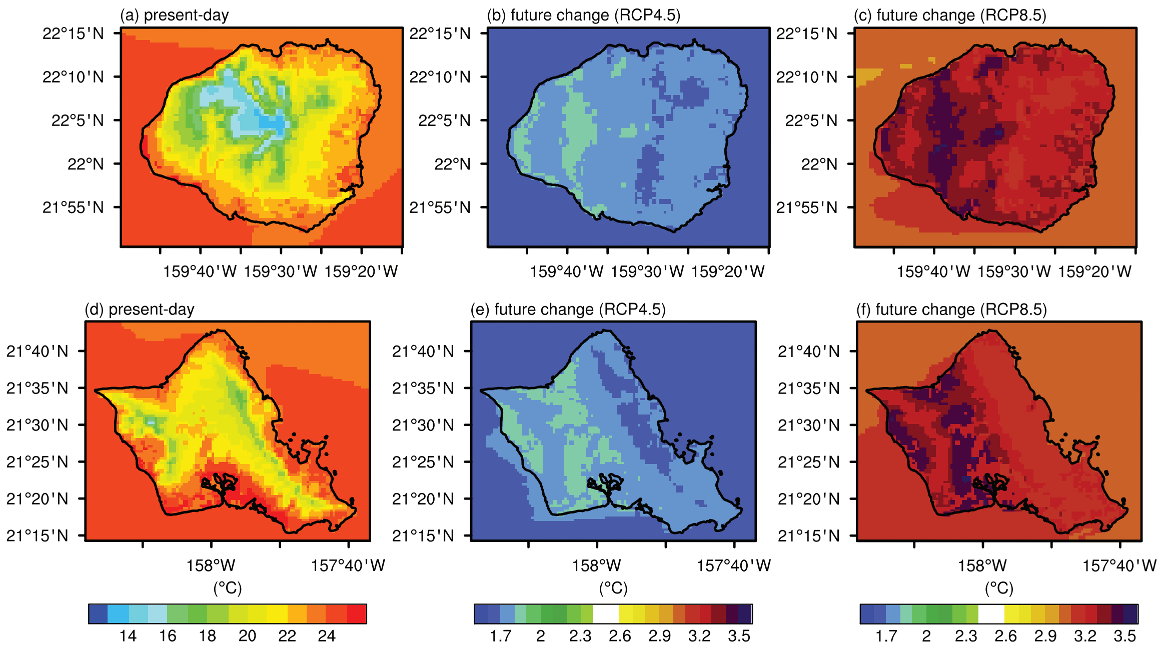

Figure 7. The simulated SAT for the present-day (a, d), the future change for RCP4.5 (b, e) and the future change for RCP8.5 (c, f), respectively. All grids for the future changes are statistically significant at 95% confidence level.

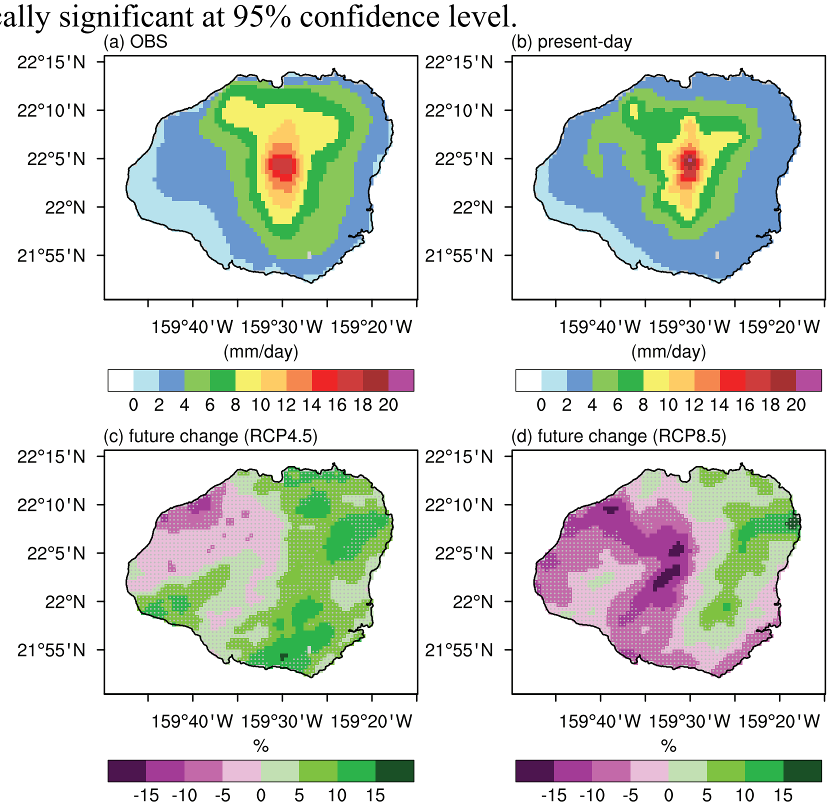

Figure. 8. The observed (a) and simulated (b) 20-yr mean rainfall for Kauai. The projected future changes are shown in (c) for RCP4.5 and (d) for RCP8.5. The grey dots indicate the future changes are not statistically significant at the 95% confidence level.

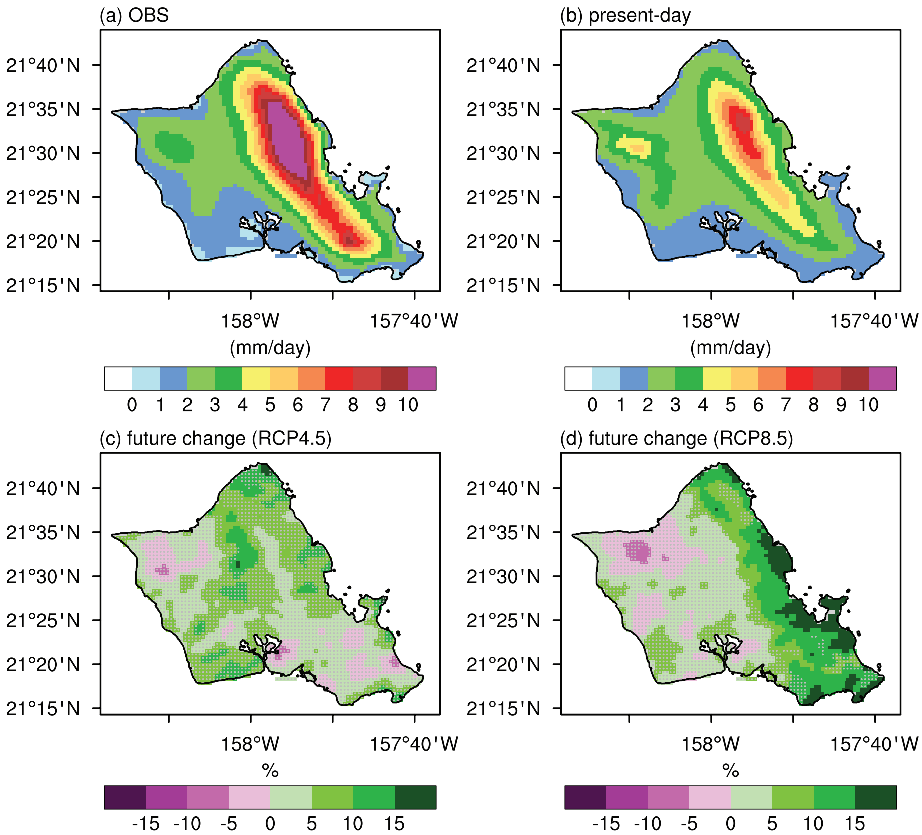

Figure 9. Same as Fig. 8 but for Oahu.

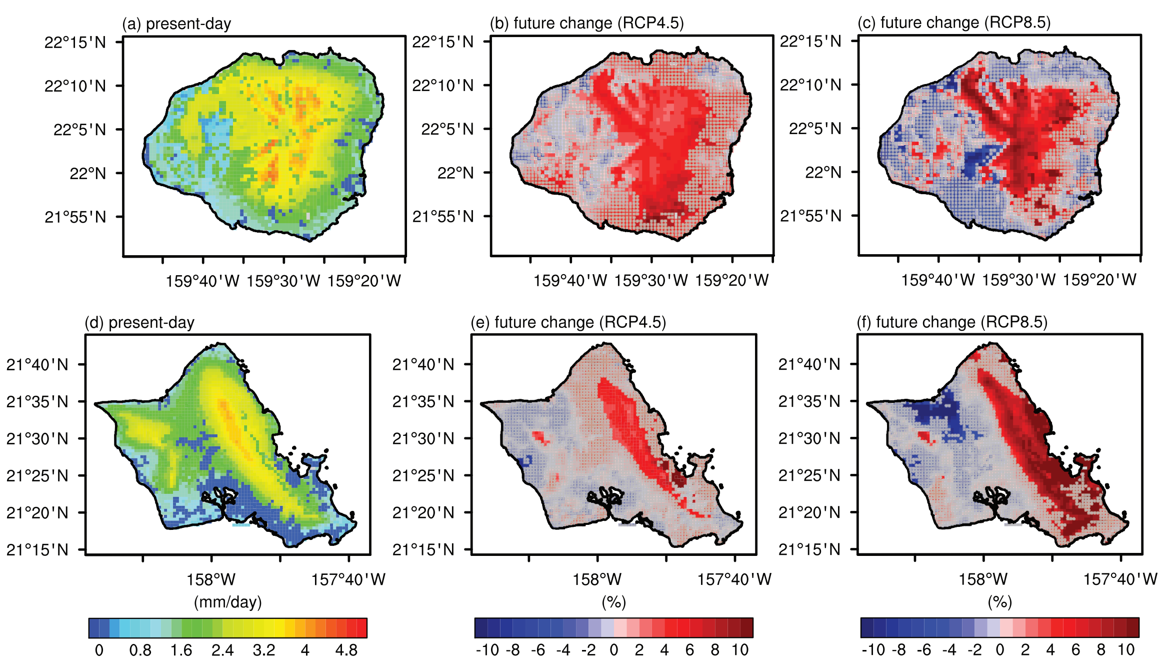

Figure 10. Same as Fig. 7 but for the evapotranspiration. The grey dots indicate the future changes are not statistically significant at the 95% confidence level.

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